NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3023

RESULTS OF EDGE-COMPRESSION TESTS ON STIFFENED FLAT-SHEET PANELS OF ALCLAD AND NONCLAD 14S-T6, 24S-T3, AND 75S-T6 ALUMINUM ALLOYS

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SUMMARY

This investigation was made to augment data previously obtained on the compressive strengths of stiffened flat-sheet panels to include the range where ultimate strengths approach the compressive yield strengths of the materials. The sheet materials used were alclad and nonclad 14S-T6, 24S-T3, and 75S-T6. The ultimate strengths of the panels tested varied from 93.3 to 118.0 percent of the compressive yield strengths of the materials from which they were constructed. The ultimate strengths of these panels appear to be limited by the strengths of the rivets. Higher ultimate strengths might have resulted from the use of larger or stronger rivets or a smaller rivet spacing.

INTRODUCTION

A series of tests has been made comparing the compressive strengths of stiffened flat-sheet panels made from several of the high-strength alclad aluminum alloys. The test results did not rank the materials in the same order as the yield strengths. It is believed that the higher strength coating on the 14S-T6 improved its strength under compressive loads more than the coatings used on 24S-T3 and 75S-T6. The compressive strengths of the panels tested were from two-thirds to three-fourths of the compressive yield strengths of the materials from which they were made. A new series of specimens with another type of stiffener that would develop compressive strengths near the compressive yield strengths has now been tested.

It was the object of this present investigation to augment the data previously obtained on the compressive strengths of stiffened flat-sheet panels to include the range where ultimate strengths approached the compressive yield strengths of the materials. In addition, the relative strengths of panels made from alclad and nonclad sheet of the same alloy were to be obtained.

This work was done by the Aluminum Company of America and has been made available to the National Advisory Committee for Aeronautics for publication because of its general interest.

MATERIAL AND SPECIMENS

The details of the stiffened panels are shown in figure 1. The unsupported width-to-thickness ratio of the sheet is about 11 and that of the flat portion of the stiffener is about 8. It was believed that these ratios would allow the development of ultimate compressive stresses approximating the compressive yield strengths of the materials used. Six stiffened panels were tested, one each made from the following aluminum alloys: alclad and nonclad 14S-T6, 24S-T3, and 75S-T6.

The sheet used was 0.156-inch-thick alclad and nonclad material. This sheet was obtained as 14S-T6, 24S-T3, and 75S-T6. The stiffeners had the nominal dimensions and the section elements shown in figure 2. They were formed from 14S-T4, 24S-T3, and 75S-0 alclad and nonclad sheet of 0.091-inch thickness. The stiffeners formed from 14S-T4 and 75S-0 were aged and heat-treated and aged to 14S-T6 and 75S-T6, respectively. The rivets used were A17S-T3 button-head rivets 3/16 inch in diameter and 7/16 inch in length.

The sheet thickness was nominally 0.156 inch, but it varied from 0.151 to 0.157 inch, and the thickness of the sheet from which the stiffeners were formed was nominally 0.091 inch, but it varied from 0.092 to 0.094 inch. Both are within commercial tolerances. The variation in section areas of the specimens as determined by weight was about ± 1.1 percent from the average.

Considerable care was taken in the forming of the stiffeners and in the assembly of the specimens in order that the differences in the material strengths might not be overshadowed by the dimensional differences of the specimens.

Before the specimens were tested, the ends were carefully machined flat and parallel. The panels were clamped flat against the carriage of the planer during machining.

The cross-sectional areas were calculated from the nominal densities of the materials, the lengths, and the net weights of the specimens. The specimen lengths were measured with a steel scale to the nearest 0.01 inch before testing, and the gross weights were determined to the nearest 0.01 pound. The computed weight of the rivet heads was subtracted from the gross weight of the specimen to obtain the net weight. The densities used are those given in reference 1.

The mechanical properties of the materials used in constructing the specimens are listed in table I. The values obtained for tensile yield strength range from 4.9 to 32.2 percent higher than the typical values listed in reference 1.

METHOD OF TEST

The specimens were tested in edge compression in a 300,000-pound-capacity Amsler hydraulic-type testing machine[1] using hardened steel platens made from EA1-50 steel forgings. Before the tests, the platens were alined essentially parallel by means of special leveling rings under one head. Dial-gage readings taken at the four corners of the platens showed that the platens were parallel within 0.0005 inch in 16 inches.

In some of the specimens there was a slight initial warp in the sheet caused by the riveting of the stiffeners to the sheet. These specimens were flattened by clamping against straight edges. In the testing machine they were held flat under a small load by the end friction. The straight edges were then removed, and the specimens rechecked for flatness. All of the specimens were thus assumed to be substantially flat when tested. Figure 3 shows a testing arrangement typical of that employed.

Type A Huggenberger tensometers[2] operating on a 1-inch gage length were used at the edges of the specimens to insure uniform distribution of load. The maximum difference in reading in any test for a stress increment of approximately 16,000 psi was 0.13 inch. This represents a maximum difference in strain of about 0.0001 in./in. or a stress difference of about 1,000 psi for the four corners at the indicated stress.

Electrical resistance wire SR-4 strain gages were used for measuring longitudinal strains in the sheet at the center of each specimen. A Baldwin-Southwark SR-4 portable strain indicator was used in conjunction with the electrical strain gages. One gage was mounted on each side of the sheet at the center of the specimen. Individual strain readings were taken on the gages, so that the bending stress in the sheet as well as the average stress could be determined.

Deflections of the sheet relative to the stiffeners were measured in the panel adjacent to the center panel by means of the apparatus shown in figure 4. Readings on the dial indicator were taken on boundary rivet lines of the panel and at the center of the panel for each increment of load applied. The readings were taken at six stations spaced 1 inch apart

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[1]Type 150 SZBDA, Serial No. 5254. The periodic calibrations of this machine show the errors in load readings to be less than 1 percent.

[2]Multiplication ratio equals 1200±.

longitudinally. The first station was $2\frac{1}{16}$ inch from the top of the specimen. Deflection readings were abandoned after the first two tests (specimens 41 and 44) because the differences in readings were not greater than the variation in duplicate readings. The deflection of the sheet with respect to adjacent stiffeners was essentially negligible up to the ultimate load.

The load was applied in increments which were reduced once yielding began. Readings of strain and deflection were made at each load. Permanent strains were determined by readings taken at a low load following each successive increment of load. These readings at low load were begun when the upper limit of the elastic range was approached and were continued to the failure of the specimen.

DISCUSSION OF RESULTS

The panels are listed in order of their decreasing ultimate compressive strengths in table II. The ultimate strengths of the panels varied from 93.3 to 118.0 percent of the compressive yield strengths of the materials from which they were constructed. The bare 75S-T6 specimen shows the highest strength of the panels tested, its superiority varying from about 6 to 26 percent over 14S-T6 and 24S-T3, respectively. The nonclad specimens of 75S-T6 and 14S-T6 show somewhat higher strengths than the alclad specimens of these alloys; however, the alclad 24S-T3 panel shows a higher strength than the nonclad 24S-T3 panel. This latter order is the reverse of the published typical yield strengths for the materials, but is in the same order as the actual average yield strengths of sheet and stiffener materials as can be seen in table I.

A typical failure for the type of specimen tested is shown in figure 5. Buckling of the sheet and stiffener occurred simultaneously at the ultimate load for each specimen. Accompanying the outward buckling of the sheet and stiffener flanges was a lateral buckling of the stiffener walls.

Failures of the alclad and nonclad 75S-T6 and 14S-T6 specimens were accompanied by failure of several rivets attaching the sheet and stiffeners. The number of rivets that failed in any row varied from zero to four, with some rivets failing in most of the rows of attachment. Where no rivet failure was visible, there were noticeable longitudinal cracks in the stiffener running under or alongside the rivet heads.

The alclad and nonclad 24S-T3 panels showed no rivet failures, but the stiffeners of the alclad specimen showed longitudinal cracks adjacent to the buckle. The nonclad specimen exhibited no splitting, but showed a marked deformation of the stiffener characterized by a pulling of the flange against the rivet heads.

Average stress-strain data as shown in figure 6 are similar in form to the compressive stress-strain data for the materials used. This behavior is reasonable since the specimens were designed to fail at the yield strengths of the materials.

The strain-difference data of figure 7 indicate the amount and direction of bending in the specimens. It can be seen that in each case the panel of alclad material tends to bend more gradually than the nonclad panel of the same alloy. The direction of bending was generally consistent with the direction of the initial bow in the specimen. To facilitate comparisons, the ordinates in figures 6 and 7 are plotted as average stress rather than total load.

From the theory for buckling, the critical buckling stress for thin sheet panels supported along the edges and loaded on the other two edges may be defined by an equation of the type,

$$S_c = KE_e\left(\frac{t}{b}\right)^2 \tag{1}$$

in which

S_c critical buckling stress, psi

E_e effective modulus, psi

K coefficient depending on loading conditions and methods of support

$\frac{t}{b}$ ratio of thickness of sheet to its effective width

The critical buckling stresses computed by equation (1), taking[3] K as 3.4 and using the secant modulus as the effective modulus, range up to three times the ultimate strengths obtained in this investigation. No simple relation was found to exist between ultimate strengths and stresses computed from equation (1) in which either the secant modulus or the tangent modulus was used as the effective modulus. On the basis of the above comparisons and the type of failure observed, it is believed that no direct association exists between the critical buckling stresses and the failures of these panels.

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[3]For loaded edges fixed and unloaded edges simply supported, see reference 2.

The rivet failure already described suggested that perhaps column action of the sheet between the rivet fastenings was responsible for failure. The strength of a column may be defined by an equation of the type,

$$\frac{P}{A} = \frac{\pi^2 E_t}{\left(\frac{KL}{r}\right)^2} \tag{2}$$

in which

P ultimate column load, lb

A cross-sectional area of specimen, sq in.

E_t tangent modulus for material, psi

$\frac{KL}{r}$ effective slenderness ratio

Curves of stress against tangent modulus were plotted for each material, and values of KL/r were computed for several combinations of tangent modulus and stress to obtain the curves shown in figure 8. The ultimate strength of each specimen is indicated on the curve for the material from which it was made, defining the effective slenderness ratio that must have existed at failure. The values of these effective slenderness ratios range from 14.5 to 22.5 and average 18.5.

If L is taken as some multiple of the rivet spacing, r is taken as the radius of gyration of the sheet, and K is taken as 0.5 (column with fixed ends), a comparison of the above indicated values can be made with computed values. The values of KL/r for a length of one, two, and three rivet spacings based on nominal sheet thickness are 8.3, 16.6, and 24.9, respectively, as indicated in figure 8.

The values of KL/r for the six specimens are seen to group near the value computed for a length of two rivet spacings. As previously noted, failure in each specimen was accompanied by either failure of several rivets, cracking of the stiffener flange beneath and around the rivet heads, or by a marked deformation around the rivet heads. These rivet failures and cracking or deformation of the stiffener may have permitted sufficient movement around an intermediate rivet to render it ineffective in supporting the sheet. A column length of two rivet spacings must have resulted which governed the failure observed. The values of KL/r at ultimate panel strengths average higher than the value computed. This may be a result of the fact that the value of K is actually greater than the 0.5 used in computation. It is assumed that any failure of more than one rivet or failure of the stiffener beneath more than one rivet along any rivet line is a result of the "follow through" after initial failure. Computed values of column strength of the sheet for the specimens tested assuming a column length of two rivet spacings are listed in table II.

The ultimate strengths of these panels appear to be limited by the strengths of the rivets. Higher ultimate strengths might have resulted from the use of larger or stronger rivets or a smaller rivet spacing. Failure of the rivets is a result of a tensile loading, bending moment, and shearing force caused by the action of the buckled sheet. An evaluation of these forces is beyond the scope of this investigation. The complexities of this problem are stated in reference 3.

CONCLUSIONS

From the results of this investigation on the compressive strengths of stiffened flat-sheet panels made from alclad and nonclad high-strength aluminum alloys which were designed to fail at the compressive yield strengths of the materials, it seems reasonable to draw the following conclusions:

1. The mechanical properties of the materials used in this investigation met the requirements of the respective specifications. In general, the properties were higher than quoted typical values.

2. The panel of nonclad 75S-T6 showed the highest ultimate strength of the specimens tested. The superiority of the 75S-T6 varied from about 6 to 26 percent over 14S-T6 and 24S-T3, respectively.

3. The nonclad 75S-T6 and 14S-T6 panels showed somewhat higher strengths than the alclad panels of the same alloy.

4. The order of ultimate strengths of the panels of various alloys in this investigation was in agreement with the order of the compressive yield strengths of the materials.

5. The ultimate strengths of the panels tested varied from 93.3 to 118.0 percent of the compressive yield strengths of the materials from which they were constructed.

6. Failure of the specimens was associated more nearly with column action of the sheet between rivet fastenings than with local buckling of the sheet.

7. The ultimate strengths of these panels appear to be limited by the strengths of the rivets. Higher ultimate strengths might have

resulted from the use of larger or stronger rivets or a smaller rivet spacing.

Aluminum Company of America,
Aluminum Research Laboratories,
New Kensington, Pa., September 14, 1949.

REFERENCES

1. Anon.: Alcoa Aluminum and Its Alloys. Aluminum Co. of Am. (Pittsburgh), 1950.

2. Hill, H. N.: Chart for Critical Compressive Stress of Flat Rectangular Plates. NACA TN 773, 1940.

3. Howland, W. Lavern: Effect of Rivet Spacing on Stiffened Thin Sheet Under Compression. Jour. Aero. Sci., vol. 3, no. 12, Oct. 1936, pp. 434-439.

TABLE I.- MECHANICAL PROPERTIES OF MATERIALS USED IN STIFFENED FLAT-SHEET PANELS

Alloy and temper	Source of specimen[a]	Tensile strength		Elongation in 2 in., percent	Compressive yield strength (0.2-percent offset), psi
		Ultimate, psi	Yield (0.2-percent offset), psi		
75S-T6	Sheet Stiffener	82,900 83,200	75,700 75,300	12.5 11.0	73,900 72,500
Alclad 75S-T6	Sheet Stiffener	78,200 78,300	71,700 71,200	12.5 12.0	69,500 69,900
75S-0	Stiffener	32,600	14,600	18.5	15,400
Alclad 75S-0	Stiffener	34,300	15,100	18.0	16,100
14S-T6	Sheet Stiffener	72,400 72,300	66,200 66,600	11.5 10.5	65,100 66,200
Alclad 14S-T6	Sheet Stiffener	69,900 71,500	63,300 64,700	12.5 11.5	61,700 62,900
14S-T3	Stiffener	69,800	52,300	18.5	41,200
Alclad 14S-T3	Stiffener	72,800	55,600	18.5	46,800
24S-T3	Sheet Stiffener	73,700 65,200	55,400 51,000	20.5 20.0	45,900 41,400
Alclad 24S-T3	Sheet Stiffener	71,800 72,600	57,800 58,500	19.5 19.5	45,700 48,000

[a]All specimens were tested in direction of rolling. Source of "stiffener" specimens was sheet from which stiffeners were formed.

TABLE II.- RESULTS OF TESTS ON STIFFENED FLAT-SHEET PANELS

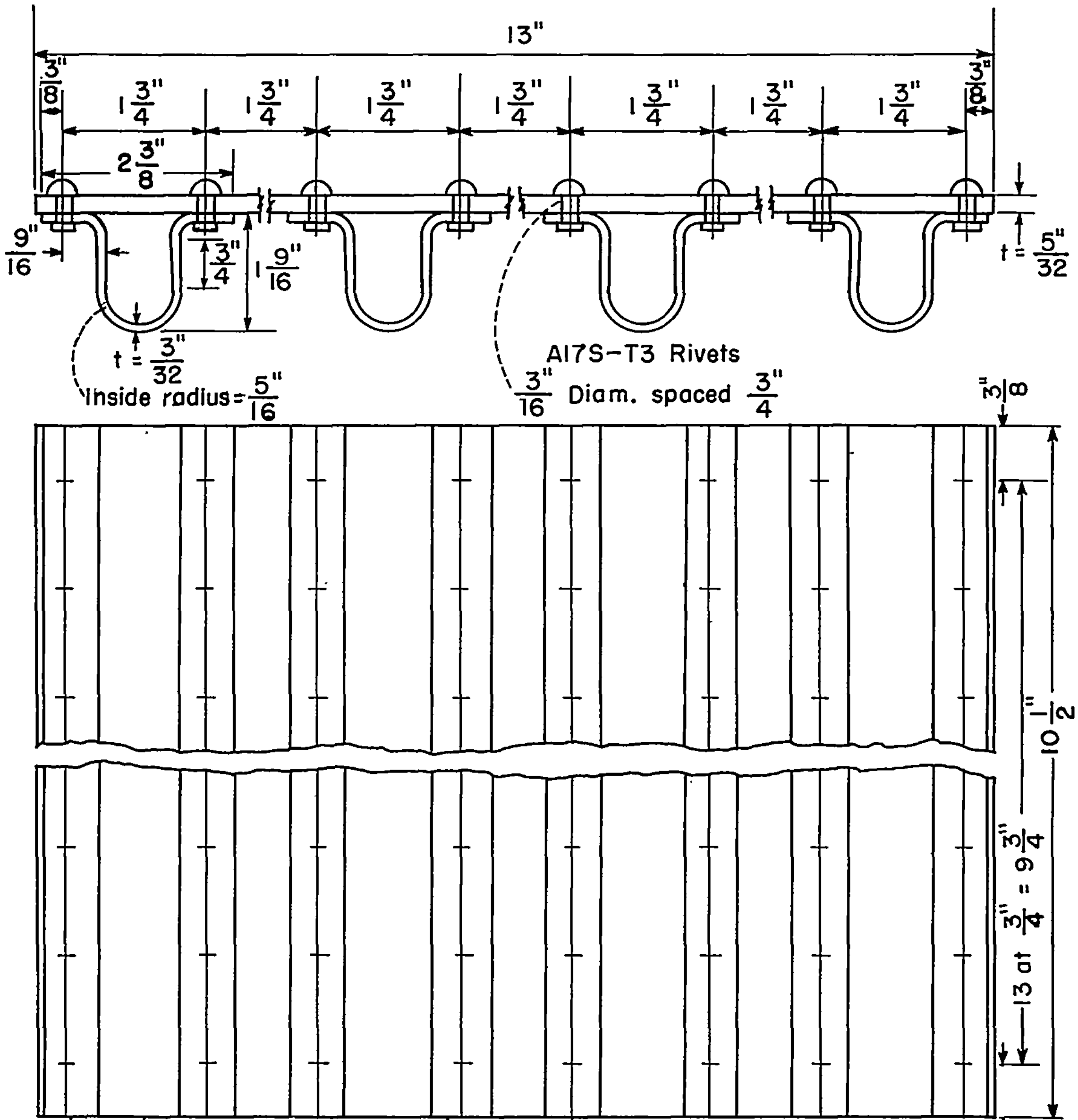
[Specimens are listed in order of decreasing strength.
Specimens were tested as columns with flat ends.]

Specimen	Alloy and temper[a]	Maximum load, P, lb	Area, A, sq in.	Maximum average stress, P/A, psi	Computed column strength of sheet,[b] P/A, psi	Compressive yield strength,[c] psi		Relative strength, percent
						Sheet	Stiffener	
45	75S-T6	260,000	3.687	70,500	73,500	73,900	72,500	100.0
44	Alclad 75S-T6	247,500	3.749	66,000	68,400	69,500	69,900	93.6
41	14S-T6	240,000	3.740	64,200	65,000	65,100	66,200	91.1
40	Alclad 14S-T6	223,000	3.674	60,800	61,400	61,700	62,900	86.2
42	Alclad 24S-T3	197,500	3.652	54,100	48,500	45,700	48,000	76.8
43	24S-T3	190,000	3.686	51,600	51,300	45,900	41,400	73.3

[a]Sheet and stiffener are both of same alloy and temper.

[b]Sheet considered as a column with fixed ends and a length equal to two rivet spacings.

[c]Taken from table I.



Spec.	Alloy of sheet and stiffeners
40	Alclad 14S-T6
41	14S-T6
42	Alclad 24S-T3
43	24S-T3
44	Alclad 75S-T6
45	75S-T6

Figure 1.- Details of panel specimens with formed stiffeners.

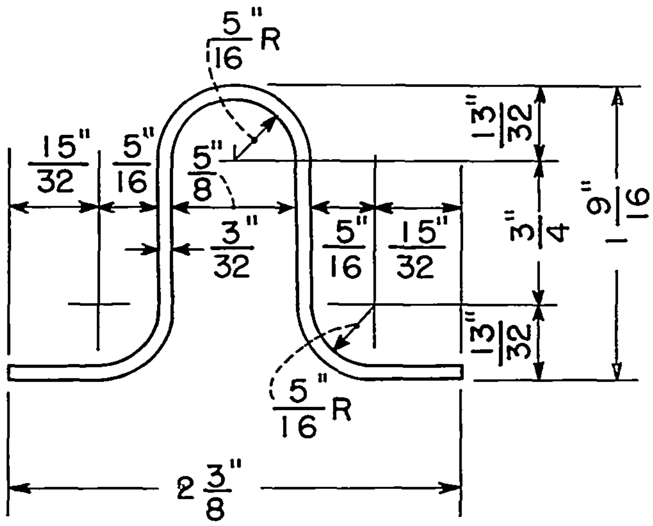


Figure 2.- Formed stiffener section. Area, 0.4402 square inch; I_{x-x}, 0.1248 inch^4; r_{x-x}, 0.5324 inch.

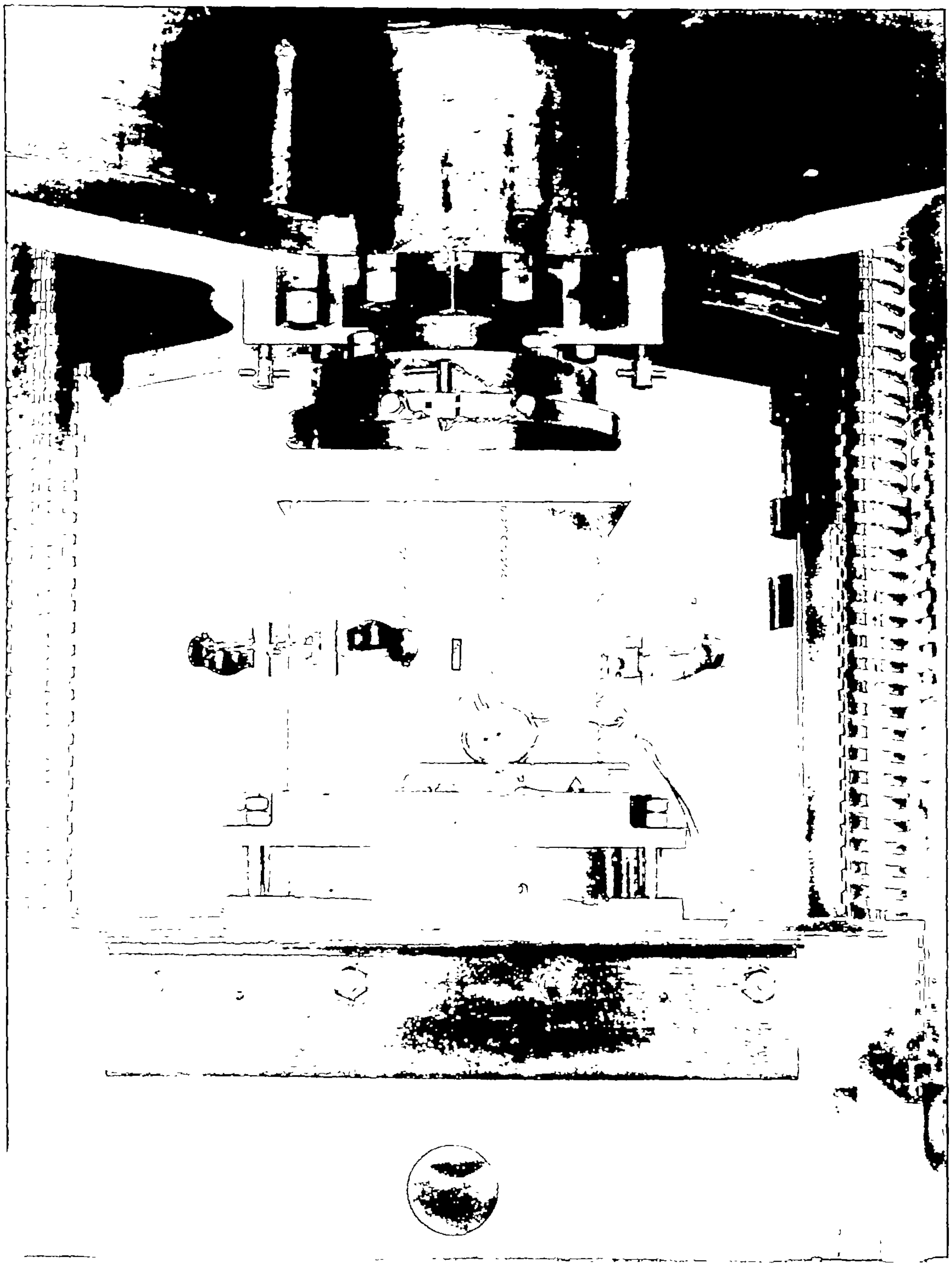


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Figure 3.- Method used in loading panels for testing. (Specimen from previous investigation.)

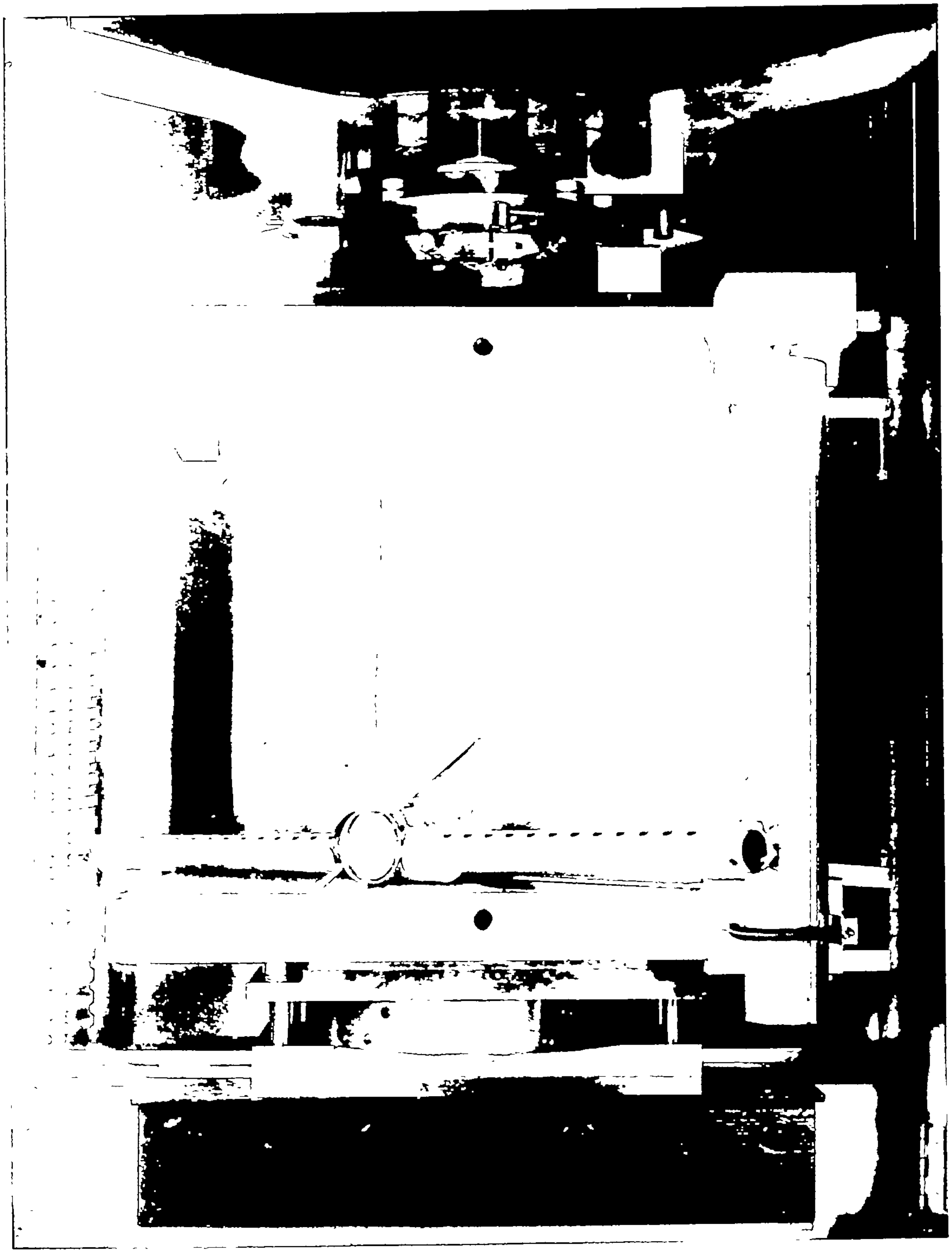

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Figure 4.- Apparatus used for measuring the deflection of the sheet relative to the stiffeners. (Specimen from previous investigation.)

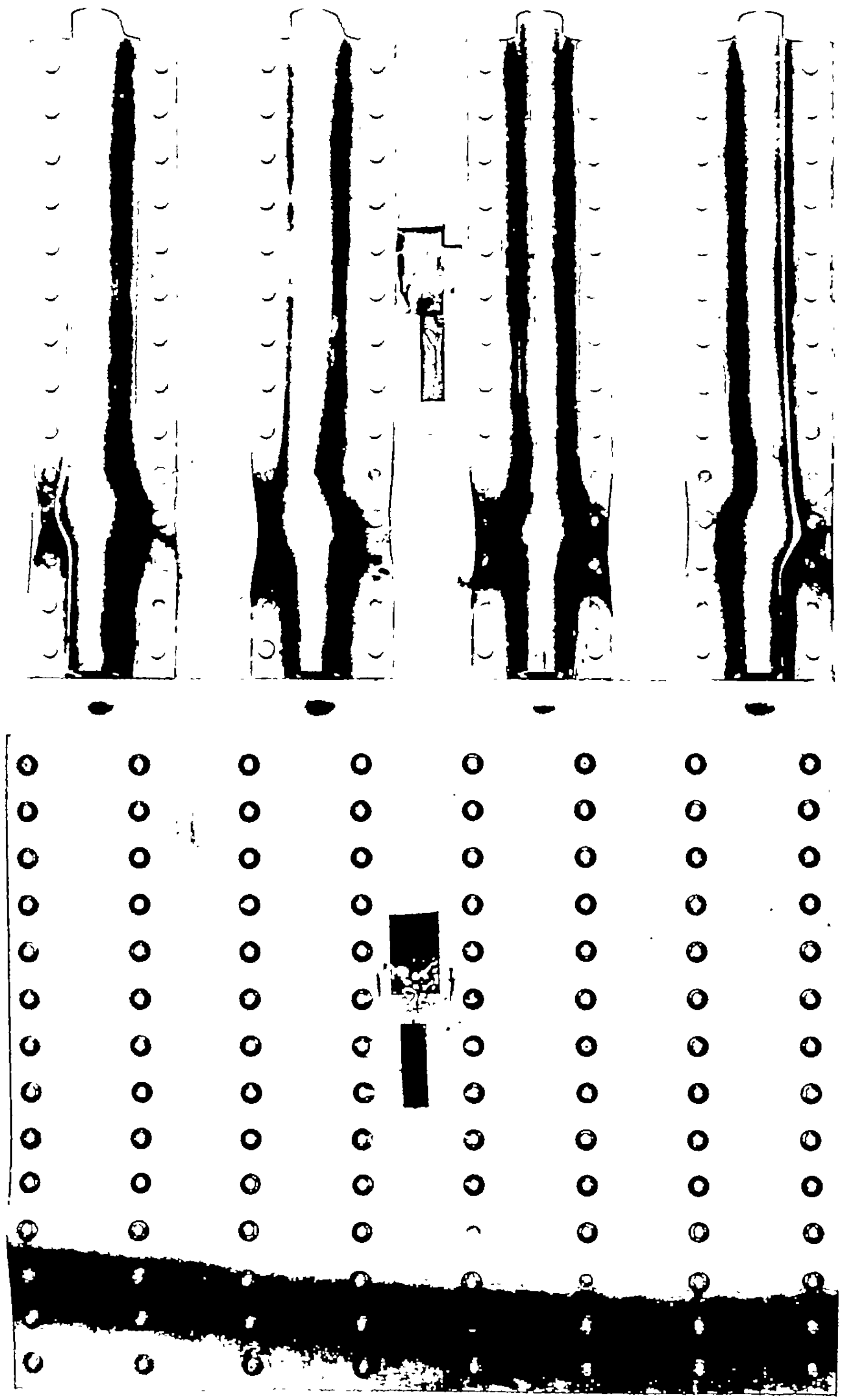

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Figure 5.- Typical failures. Top, specimen 45; bottom, specimen 41.

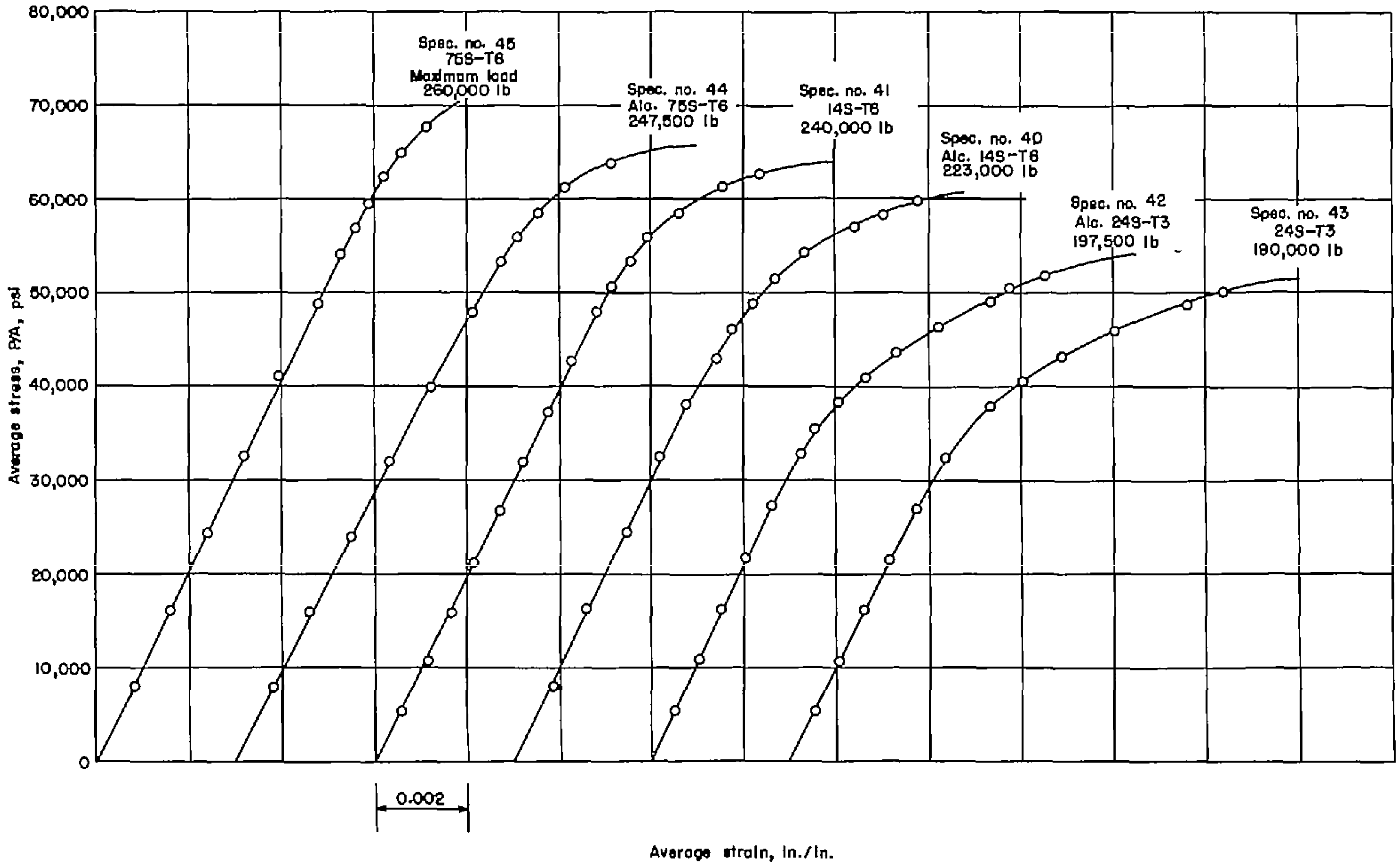

Figure 6.- Curves of average compressive stress against strain for stiffened flat-sheet panels.

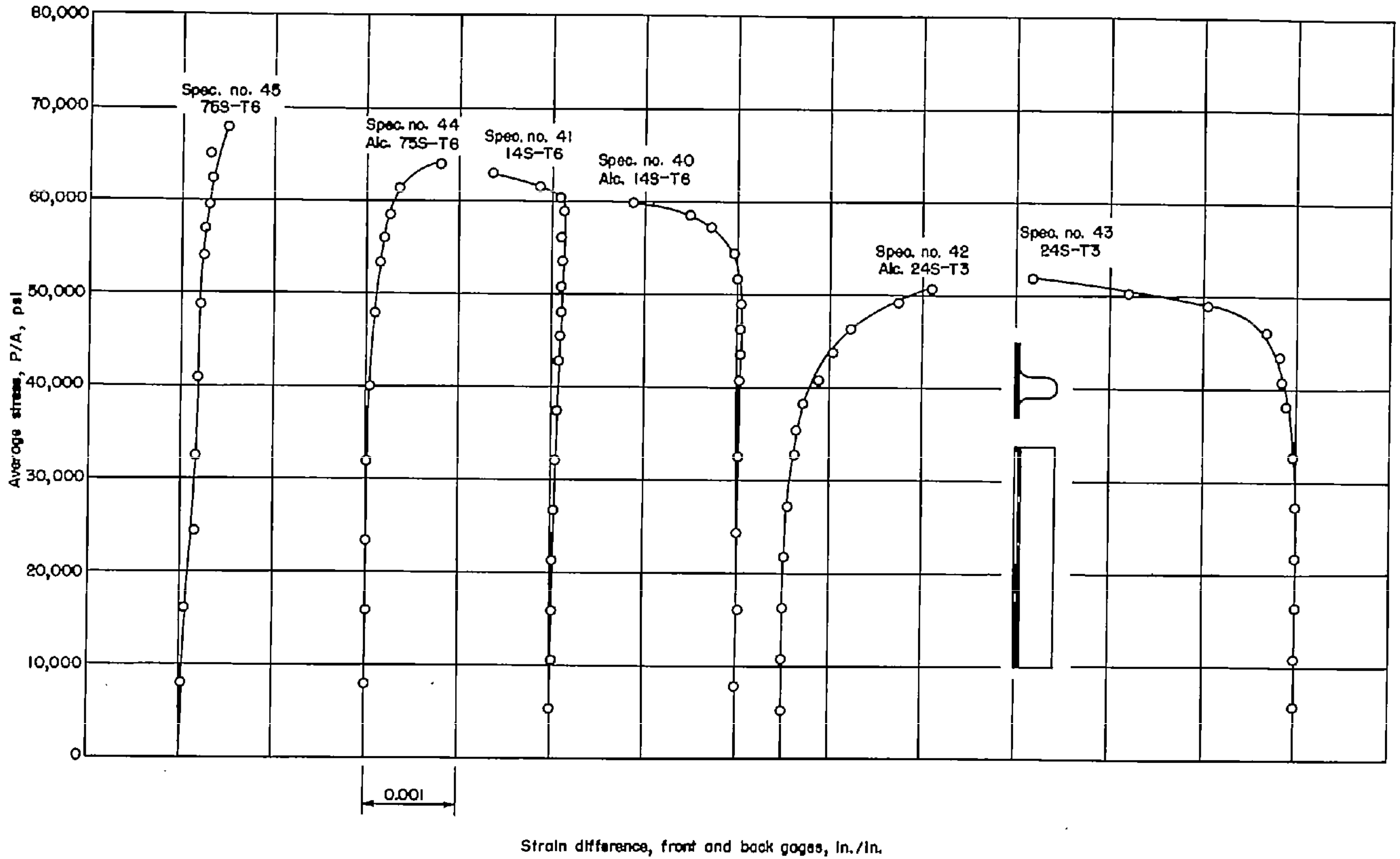

Figure 7.- Curves of average compressive stress against strain difference for stiffened flat-sheet panels.

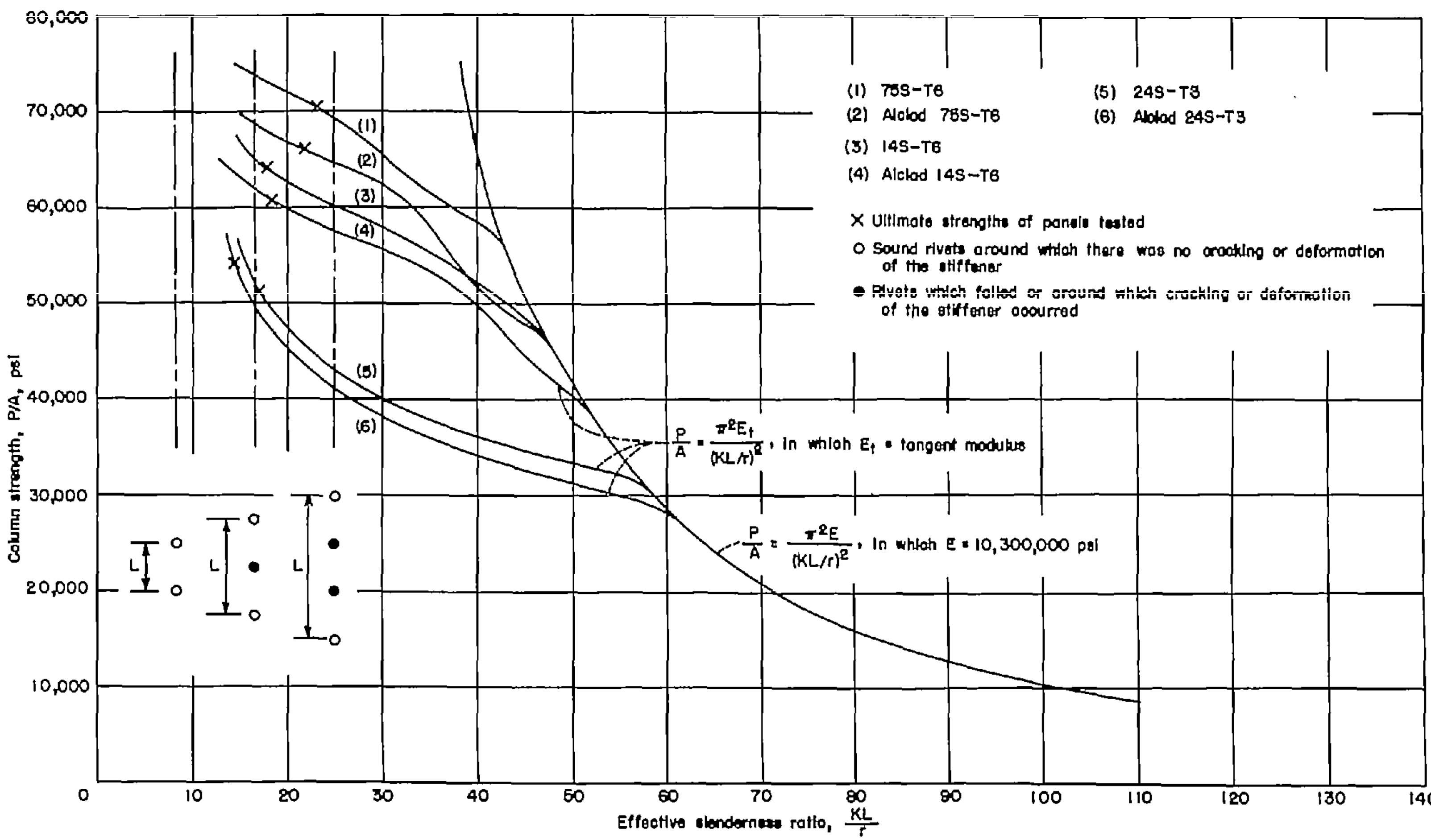

Figure 8.- Column strength of stiffened flat-sheet panels under edge compression.

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